"The Constitution of the Electric Spark." By ARTHUR SCHUSTER, F.R.S., and G. HEMSALECH. Received January 24,—Read February 2, 1899.

(Abstract.)

When an electric spark passes between metallic electrodes, the spectrum of the metal appears, not only in immediate contact with the electrodes, but stretches often across, from pole to pole. It follows that during the short time of the duration of the spark, the metal vapours must be able to diffuse through measurable distances.

The following investigation was undertaken primarily to measure this velocity of diffusion with the special view of comparing different metals, and different lines of the same metal.

Feddersen published, in the year 1862, an interesting research, in which photographs of sparks passing between different metal poles are taken after reflection from a rotating mirror. He could from his experiments draw some conclusions which have a bearing on the subject, but it was necessary for our purpose that the light should also be sent through a spectroscope, so as to distinguish between the luminous particles of air and those of the metal poles.

The method of the rotating mirror tried during the course of several years in various forms by one of us, did not prove successful. On the other hand good results were obtained at once on trying the method used by Professor Dixon, in his researches on explosive waves. This method consists in fixing a photographic film round the rim of a rotating wheel. All that is necessary for its success is to have sparks so powerful that each single one gives a good impression of its spectrum on the film. Were the sparks absolutely instantaneous, the images taken on the rotating wheel would be identical with those developed on a stationary plate, but on trial this is found not to be the case. The metal lines are found to be inclined and curved when the wheel rotates, and their inclination serves to measure the rate of diffusion of the metallic particles. The air lines, on the other hand, remain straight, though slightly widened.

To avoid the tendency of the film to fly off the wheel when fixed round its rim, as in the original form of the apparatus, a spinning disc was constructed for us by the Cambridge Scientific Instrument Company. The film is placed flat against the disc, and is kept in place by a second smaller disc, which can be screwed lightly to the first. The diameters of the two discs are 33 and 22·2 cm., the photographs being taken in the annular space of 10·8 cm., left uncovered by the smaller disc. An electric motor drives the disc, and we have obtained velocities of 170 turns per second, though in our experiments the number of

revolutions was generally about 120, giving a linear velocity of about 100 metres/second for that part of the film on which the photograph was taken.

The electric discharges were obtained from a battery of six Leyden jars, having a total capacity of 0·033 microfarad, and being charged from an induction machine constructed for us by Mr. H. C. Wimshurst. This machine has twelve plates of 62 cm. diameter, and gives sparks which are 13 inches long. The electrodes were, as a rule, placed 1 cm. apart, and an image of the spark was projected on the slit of the spectroscope, the distance of the slit from the electrodes being equal to four times the focal length of the projecting lens, so that the image was equal in size to the spark. The prism used was made by Steinheil, and had a refracting angle of 60°.

We may now pass to the description of the results obtained when the spectrum of a single spark is taken on a moving film. A preliminary trial with various metallic electrodes had shown us that the sharpest results were obtained with zinc, and we therefore chose that metal for our first investigation. The principal lines of zinc as they appear on our photographs are the double line, the least refrangible of the two having a wave-length 4924·8, and the blue triplet, the wave-length of the leading line being 4810·7. All the lines are curved on the photographs taken with the spinning disc, but the displacements, especially near the poles, are subject to considerable variations. This is probably due to the fact that the path of the metallic particles is not always straight, and, if straight, its image does not necessarily coincide with the slit. A very slight error in measurement will also affect the results considerably when the total displacement measured is small. Our results do not for this reason allow us at present to give any opinion as to the maximum velocity of the particles near the pole; but if these are considerable, they drop down very quickly to speeds which, in the case of zinc, are not far off 500 metres/second.

We have adopted two methods of comparison between different photographs. We have in the first place measured the displacements at a number of nearly equidistant points, and from these measurements we have deduced the time taken for a metallic molecule to pass from the pole to a point 2 mm. away from it. If this method could be applied in every case, it would form a rational and consistent basis of comparison. But the curved lines which are to be measured are often very diffuse near the pole; this, and the continuous spectrum, may render it impossible to obtain satisfactory measurements at that point. In order not to have to reject unnecessarily a large number of measurements because the spectrum near the pole was indistinct, we have adopted another method, which, though less rational than the first, is found to give consistent results. From all our measurements we may deduce certain figures for the molecular velocities at different and

generally equidistant points on the photographs, and may take the average of all these figures as the mean velocity of the particle. In the tables given in the paper, V_1 always refers to the mean velocity between the pole and a point 2 mm. away from it, while V_2 refers to the average velocity taken for different distances, as just explained. The influence of change of capacity and change in the length of the spark was investigated in the case of zinc, and the following table exhibits the results. As the zinc lines are sharp near the pole, the first of the above methods of measurement could be applied.

Table I.—Average Velocity (V_1) in metres/second of Zinc Molecules.

Sparking distance.	Wave-length.	Number of jars.		
		2.	4.	6.
cm.				
0·51	4925	814	556	416
	4811	1014	668	529
1·03	4925	400	499	415
	4811	501	548	545
1·54	4925	723	1061	435?
	4811	1210	1526	492?

The first striking result to be deduced from the table is the uniformly higher velocity deduced from the double line 4925, as compared with that found when one of the lines of the triplet is measured; for we have ascertained that the two first lines of the triplet are always displaced by the same amount, and the third is so much mixed up with the air lines in its neighbourhood that it cannot be measured. It was one of the objects of the investigation to detect, if possible, differences of this kind, which might be accounted for by the fact that the molecules producing different lines of the same spectrum have not necessarily the same mass. We nevertheless hesitate to ascribe the smaller apparent velocity derived from $\lambda = 4925$ to this reason. This line, as has been mentioned, is one component of a double line, and the doublet is not resolved on the photographs taken with the moving film. Near the pole where the light is strong, the edge of the least refrangible component of the doublet would be considered to be the least refrangible edge of the doublet; but near the centre of the spark the light is weaker, and the lines, owing to the motion of the wheel, are drawn out towards the violet. The most intense portion of the image will here be that part where the two lines are superposed, and in wishing to set the cross wire on the edge of the line, we should be

tempted to set it on the edge of the *most* refrangible component. There is reason to believe that this is the cause of the greater deflection of the double line, and the photographs show some signs that if this source of error is eliminated, the molecule giving out the double line moves more quickly than that giving rise to the triplet. We reserve the decision of this point until we have been able to apply greater dispersion.

Comparing the sparks obtained with different capacities, it is found that when the spark gap is small, there seems a very curious *diminution* of velocity as the capacity increases; this is not what should have been expected at first sight, as with the large number of jars we should expect higher temperatures, and therefore greater velocity of diffusion. When the spark gap is 1 cm., the experiments do not reveal any marked change due to capacity. When the gap is increased still further the sparks become very irregular and unsteady, and no certain conclusions can be drawn from our measurements; the numbers marked with a query are specially doubtful. When six jars are used practically identical numbers are obtained for all sparking distances, but with small capacity the centimetre spark seems to give a lower result than in the two other cases. While we should not like at present to consider this as an established result, the table serves to show that the centimetre spark and the highest capacity used gives the most consistent numbers, and our experiments with other metals were all made under these conditions, except in the case of bismuth, where clearer spectra were obtained with only two jars.

Comparing different metals with each other, we find in the first place that those having comparatively low atomic weights, viz., aluminium and magnesium, have higher molecular velocities. With magnesium the metal vapour is scattered about to such an extent that no measurements could be made, but the average velocity of the aluminium molecule was found to be over three times as great as that of zinc, the numbers not laying any claim to accuracy. Comparing zinc and cadmium with each other, we obtain almost identical numbers, both for the corresponding doublet and triplets.

Bismuth gave remarkable results. In spite of its high atomic weight some of the lines are but little displaced, indicating an average molecular velocity of 1420 metres/second. For other lines the velocity falls down to that of zinc and cadmium, while one line ($\lambda = 3793$) has a still smaller velocity.

We have not obtained satisfactory results with mercury; the best were those in which poles used were of zinc or cadmium, which were covered with amalgam. Differences in molecular velocities were obtained for different lines, but the result here is not so certain as with bismuth. There is obviously no simple law connecting these velocities with the atomic weight.

Dr. Feddersen was led through his researches to the conclusion that the metallic particles after being once torn off from the electrodes by the discharge took no further part in it, but were thrown irregularly into the space surrounding the electrodes quite independently of the electric current. Although in some cases, and especially with magnesium poles, there is some evidence that this is partly true, we are led to take the following modified view of the matter.

The initial discharge of the jar takes place through the air; it must do so because there is at first no metallic vapour present. The intense heat generated by the electric current volatilises the metal, which then begins to diffuse away from the poles; the subsequent oscillations of the discharge take place through the metallic vapours and not through the air. We find confirmation of this view in a striking experiment which is easily repeated. If a coil of wire be inserted in the spark circuit of a Leyden jar, which may be charged either by a Wimshurst machine or an induction coil, the air lines disappear almost completely, the metallic lines alone remaining. According to our view we should explain the experiment by saying that the coil which adds self-induction lengthens the duration of the discharge, and allows time for the metallic molecules to diffuse properly into the spark gap. A great part of the energy of the current may then do useful work by heating up the metallic molecules instead of those of air. Mr. Hemsalech is at present engaged in investigating the changes in the metallic spectra which accompany the insertion of self-induction.

The first spark passing through the air will give rise to a sound wave which, during the complete time of the discharge, will only travel a few millimetres. We may therefore consider that the mass of metallic vapours suddenly set free is driven by its own pressure into the partial vacuum formed by the heated air. It would seem more correct to liken the process to that of a gas under pressure flowing into a vacuum than to that of a pure thermal diffusion. There is not much difference between these views, and we may take it that in our experiment we have approximately measured the velocity of sound in the metallic vapours. This gives a relation between their temperature and density. If we neglect the differences in the ratio of specific heat we find approximately

$$V = 80\sqrt{T/\rho},$$

where T is the absolute temperature and ρ the vapour density referred to hydrogen. Thus for cadmium the average molecular velocity found was 560, and substituting $\rho = 56$ we obtain $T = 2700$, which seems a possible value. Hence we conclude that the molecule of cadmium in the spark cannot have a mass which is much smaller than that directly determined near the boiling point of the metal.

In conclusion we have also taken some photographs in which the slit

was directly focussed on the sensitive film without the interposition of the prism. The photographs show a straight image of the slit followed by a number of curved bands extending from both poles into the spark gap.

The straight image we consider to be the initial discharge through air creating sufficient heat to fill the space with vapour through which the oscillating discharges may then pass. Our experiments point to the fact that the periodic time was rather too small in our experiments to give the best results. The metallic molecule before it has had time to reach through a sufficient distance was possibly affected in its motion by the subsequent oscillation. We hope to remedy this defect by introducing still higher capacities than those used. Our experiments allow us to give the following approximate numerical data. The air rendered luminous by the first discharge remains luminous for a time of about 5×10^{-7} second, the metallic vapours then begin to diffuse and reach the centre of the spark (the gap being 1 cm. long) in a time which in the case of cadmium was about 6×10^{-6} second. The periodic time of the oscillations with our six jars and a circuit possessing as little self-induction as possible was about 2×10^{-6} second. The metallic vapours remain luminous in the centre of the spark for a longer period than near the poles, the duration of the time during which some luminosity can be traced with a discharge from six Leyden jars is about $1{\cdot}5 \times 10^{-5}$ second.

February 9, 1899.

The LORD LISTER, F.R.C.S., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read :—

I. "On the Reflection of Cathode Rays." By A. A. C. SWINTON. Communicated by LORD KELVIN, F.R.S.

II. "On the Recovery of Iron from Overstrain." By JAMES MUIR, B.Sc. Communicated by Professor EWING, F.R.S.

III. "A Soil Bacillus of the Type of De Bary's *B. megatherium*." By W. C. STURGIS, M.A., Ph.D. Communicated by Professor MARSHALL WARD, F.R.S.